DROP-ON-DEMAND INK-JET PRINTING HEAD

BACKGROUND OF THE INVENTION

The present invention relates to a drop-on-demand ink-jet printing head for jetting ink, in the form of small droplets, from an ink reservoir so as to form printed dots on recording paper.

Drop-on-demand ink-jet printing head can be classified into three main types. The first type is a so-called <u>bubble</u> jet type in which a heater for instantaneously vaporizing ink is provided on the top end of a nozzle to thereby produce and jet ink drop by expansion pressure created during vaporization. In the second type, a piezoelectric element provided in a vessel constituting an ink reservoir flexes or expands in accordance with an electrical signal applied thereto so as to jet ink in the form of a drop by a force produced when the element expands. In the third type, a piezoelectric element is provided in an ink reservoir in opposition to a nozzle so as to jet an ink drop by dynamic pressure produced in a nozzle area upon expansion of the piezoelectric element.

As disclosed in Japanese Patent Publication No. Sho-60-8953, the above-mentioned third type drop-on-demand ink-jet printing head has a configuration wherein a plurality of nozzle apertures are formed in a wall of a vessel constituting an ink tank, and piezoelectric elements are disposed at the respective nozzle apertures matched in the direction of their expansion

and contraction with each other.

In this printing head, a printing signal is applied to the piezoelectric elements so as to selectively actuate the piezoelectric elements to jet ink drops from the corresponding nozzles by the dynamic force produced when the piezoelectric elements are actuated to thereby form dots on printing paper.

In such a printing head, it is desirable that the efficiency in ink drop formation and the force of ink drop jetting are large. However, since the unit length of a piezoelectric element and the rate of expansion/contraction of the same per unit voltage are extremely small, it is necessary to apply a high voltage to in order to obtain sufficient jetting force for printing, and it is therefore necessary to construct a driving circuit and electric insulators so as to withstand such a high voltage.

In order to obtain a high jetting force, European Patent Unexamined Publication No. 372521 discloses a drop-on-demand ink-jet printing head in which a piezoelectric plate is fixedly attached to an elastic metal plate and is cut and divided corresponding to the arrangement of nozzle apertures, with one end of the piezoelectric plate being fixed to a frame while the other end thereof opposite to the nozzle apertures is a free end.

In this printing head, a driving signal is applied to the piezoelectric plate to thereby bend the elastic metal plate to

store energy. In this state, the application of the driving signal is stopped to thereby release the elastic force stored in the elastic metal plate so that dynamic pressure is applied to ink, creating a repulsion force to thereby discharge the ink in the form of ink drops to the outside through the nozzle apertures.

However, there is a problem in that a high voltage has to be applied to the piezoelectric plate to bend the elastic metal plate to such an extent as to form ink drops.

SUMMARY OF THE INVENTION

It is an object of the present invention to solve the foregoing problems of the prior art.

It is another object of the present invention to provide a drop-on-demand ink-jet printing head with which ink drops can be produced at a low voltage and with a high energy efficiency.

In order to attain the foregoing objects, according to the present invention, a drop-on-demand ink-jet printing head is provided which comprises: an array of a plurality of piezoelectric elements arranged at regular intervals and fixed at their one ends to a base, the other ends of the respective piezoelectric elements being free ends which are disposed in opposition to respective nozzle apertures, the piezoelectric elements being formed by cutting, at predetermined width, a piezoelectric plate obtained by firing a lamination of paste-like piezoelectric material conductive material stacked

alternately in layers; and ink reservoir portions formed between the nozzle apertures and the free ends of the piezoelectric elements.

In the printing head constructed according to the present invention, a piezoelectric plate is formed by firing a lamination of paste-like piezoelectric material conductive material stacked alternately in layers and is cut at predetermined widths into pieces to thereby constitute the array of piezoelectric elements. Accordingly, even if a low voltage is selectively applied to the piezoelectric material layers constituting the respective piezoelectric elements to thereby drive the layers, the sum of the respective force components acts on ink, so that it is possible to produce enough dynamic pressure to jet the ink as ink drops through the corresponding nozzle apertures. Since the array of piezoelectric elements can be formed by cutting into strips the piezoelectric plate fixed to a base or the like, extremely small vibration elements can be produced with high working accuracy and with high efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective sectional view illustrating the structure of a main part of a drop-on-demand ink-jet printing head of a first type constructed in accordance with the present invention;

Fig. 2 is a sectional view illustrating the structure of

a printing head according to the present invention;

Fig. 3a to 3f are explanatory diagrams illustrating steps of producing a piezoelectric vibrator;

Fig. 4 is a perspective view illustrating the structure of a vibrator unit produced by the steps shown in Figs. 3a to 3f;

Fig. 5 is a perspective view illustrating another embodiment of a drop-on-demand ink-jet printing head of the first type according to the present invention, in which a nozzle plate is removed;

Figs. 6a and 6b are sectional views illustrating the structure of a drop-on-demand ink-jet printing head of a second embodiment according to the present invention;

Figs. 7a and 7b are perspective views illustrating a method of producing an array of piezoelectric elements for use in the apparatus of Fig. 6;

Fig. 8 is a perspective view illustrating another embodiment of the array of piezoelectric elements;

Figs. 9 to 11 are perspective views illustrating a method of attaching an array of piezoelectric elements onto a base plate;

Figs. 12 to 14 are perspective views illustrating an embodiment of the nozzle plate for use in the printing head according to the present invention;

Fig. 15 is a sectional view illustrating an example of a material base plate suitable for producing, by etching, the

nozzle plate shown in Figs. 12 to 14;

Fig. 16 is a perspective view illustrating another embodiment of the nozzle plate;

Fig. 17 is a sectional view illustrating a printing head using the nozzle plate shown in Fig. 16;

Fig. 18 is a sectional view illustrating another embodiment of the state of attaching a nozzle plate;

Fig. 19 is a plan view illustrating an embodiment in which support members for supporting a nozzle plate are formed by use of a piezoelectric plate at the same time;

Fig. 20 is a sectional view illustrating a printing head using a piezoelectric element array shown in Fig. 19;

Figs. 21a and 21b are sectional views respectively illustrating another state of attaching a nozzle plate and the operation thereof at the time of forming an ink drop;

Figs. 22a to 22c are diagrams respectively illustrating an embodiment in which an elastic material such as bonding agent fills space portions of piezoelectric elements;

Figs. 23a and 23b are sectional views illustrating the ink-jet printing head of a third type according to the present invention;

Figs. 24a to 24c are explanatory diagrams illustrating steps of forming the array of piezoelectric elements for the apparatus shown in Figs. 23a to 23b;

Figs. 25a and 25b are explanatory diagrams illustrating

another embodiment of the inventive method of forming the array of piezoelectric elements;

Fig. 26 is a sectional view illustrating a printing head using the array of piezoelectric elements produced by the process shown in Figs. 25a and 25b;

Figs. 27a to 27c are explanatory diagram illustrating another method of forming an optimum array of piezoelectric elements for the printing head shown in Figs. 23a and 24b;

Fig. 28 is a perspective view illustrating an embodiment of a nozzle plate suitable for the array of piezoelectric elements shown in Fig. 27c;

Fig. 29 is a sectional view illustrating a printing head employing the piezoelectric element array shown in Fig. 27c and the nozzle plate shown in Fig. 28;

Figs. 30a and 30b are sectional views illustrating an embodiment of the printing head of a fourth type according to the present invention;

Figs. 31a to 31c are explanatory diagrams illustrating a first embodiment of a method of producing lead pieces suitable for the printing head shown in Figs. 30a and 30b; and

Figs. 32a to 32c are explanatory diagrams illustrating a second embodiment of the method of producing lead pieces suitable for the printing head shown in Figs. 30a and 30b.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1 and 2 depict a drop-on-demand ink-jet printing

head of a first type according to the present invention. In the drawings, a base 2 has sidewise extended projection portions 2a and 2a at its one end portion, that is, at its lower portion in the drawings, so that piezoelectric vibrators 12 and 12' (which will be described later) are fixed to the projection portions 2a and 2a.

On the upper surface of the base 2 is fixed a vibration plate 4 for separating an ink reservoir and the piezoelectric vibrators 12. Concave portions 4a and 4a are formed in the vibration plate 4 in the vicinity of portions where the vibration plate 4 contacts the piezoelectric vibrators 12 so that the vibration plate 4 can be respond easily to the vibration of the piezoelectric vibrators 12.

A spacer member 6, which acts also as a channel constituent member, is fixed to the surface of the vibration plate 4. In the spacer member 6, recess portions 6a constituting ink reservoirs in cooperation with the vibration plate 4 are provided in the areas opposite to the piezoelectric vibrators 12. In a nozzle plate 8 (which will be described later) recess portions 6b constituting ink supply channels are formed so that the recess portions 6a constituting the ink reservoirs, nozzle apertures and the recess portions 6b constituting the ink supply channels communicate with each other through respective penetration holes 6c and 6d. The nozzle plate 8 is fixed to the surface of the spacer member 6,

and in the nozzle plate 8, a plurality of nozzle apertures 10 and 10′ are formed so as to accord with the arrangement of the piezoelectric vibrators 12 and 12′. The respective openings of the recess portions 6b formed in the spacer member 6 are sealed by the nozzle plate 8 so as to form the ink supply channels.

The respective one end portions of the above-mentioned piezoelectric vibrators 12 and 12′ are fixed to the vibration plate 4, and the respective other end portions of the same are fixed to the projection portions 2a.

Figs. 3a to 3f illustrate a method of producing the above-mentioned vibrators.

A thin coating of a piezoelectric material in paste-like form, for example, a titanic-acid/zirconic-acid lead-system composite ceramic material, is applied on a surface plate 20 to thereby form a first piezoelectric material layer 21 (in Fig. 3a). A first conducive layer 22 is formed on the surface of the first piezoelectric material layer 21, while a part of the first piezoelectric material layer 21 is left as an exposed portion 21a (in Fig. 3b). Further, a thin coating of a piezoelectric material is applied on the respective surfaces of the conductive layer 22 and the exposed portion 21a of the first piezoelectric material layer 21 to thereby form a second piezoelectric material layer 23. A conductive layer 24 is further formed on the other surface of the layer 23 opposite the surface on which the conductive layer 21a has been formed

(in Fig. 3c). The above steps are repeated a required number of times.

In the stage where a predetermined number of layers have been formed in the form of a lamination in such a manner as described above, the lamination is dried and fired under pressure at a temperature in a range of 1000°C to 1200°C for about an hour, thereby obtaining a plate-like ceramic member 25. One end portion of the ceramic member 25 where the conductive layer 24 is exposed is coated with a conductive paint to thereby form a collecting electrode 26, and the other end portion of the ceramic member 25 where the conductive layer 22 is exposed is coated with a conductive paint to thereby form a collecting electrode 27 (in Fig. 3d) to thereby form a piezoelectric plate 28. The thus-formed piezoelectric plate 28 is fixed onto the projection portion 2a of the base 2 through a conductive bonding agent (Fig. 3e). Then, the piezoelectric plate 28 is cut, by a diamond cutter or the like, in the vicinity of the surface of the base 2, to thereby divide it in predetermined widths into a plurality of vibrators 30 (in Fig. 3f).

Thus, there is formed an arrangement of the piezoelectric vibrators 30 (corresponding to the piezoelectric plate 12 and 12 in Fig. 1), the respective one-end portions of which are fixed to the base 2, and the other free end portions of which are separated by slits 29 produced by the above-mentioned

cutting process. The steps shown in Figs. 3e and 3f are also applied to the opposite surface of the base 2, whereupon a vibrator unit as shown in Fig. 4 is formed.

Individually separated conductive members are connected to the respective collecting electrodes 26 which are connected to the one-side electrodes of the respective piezoelectric vibrators 30, of the thus-arranged vibration unit, while a common conductive member is connected to the collecting electrodes 27 which are respectively connected to the other-side electrodes. Alternatively, in the case where the vibration plate 4 is made of a conductive material, the vibration plate 4 is employed as the common conductive member.

If an electric signal of about 30 V is applied between the conductive members, the piezoelectric vibrators 29, to which the signal is selectively applied through their proper conductive members, expand in their axial directions as a result of application of the actuating voltage to the respective piezoelectric material layers.

In this embodiment, since the electrodes are disposed parallel to each other in the expansion direction, the energy efficiency is high in comparison with those of other vibration modes.

The vibration plate 4 fixed to the top ends of the piezoelectric vibrators 12 expands so that the vibration plate 4 contact the piezoelectric vibrators 12 is displaced in the

direction toward the recess portions 6a constituting the ink reservoirs, thereby compressing the ink reservoirs. The ink on which the pressure is exerted through the volume reduction of the ink reservoirs reaches the corresponding nozzle apertures 10 through the penetrating holes 6c and jets out as ink drops.

When the application of the signal is stopped, the piezoelectric vibrators 12 contract so that the vibration plate 4 also returns to its initial position. Consequently, the ink reservoir is expanded to the volume at the time when no signal is applied, so that the ink in the recess portion 6b flows into the recess portion 6a through the penetrating hole 6d, thereby preparing for the next ink drop generation.

According to this embodiment, the ink reservoirs compressed by the piezoelectric vibrators 12 and 12′ are connected with the nozzle apertures 10 and 10′ through ink channels such as the penetrating holes 6c and 6c, so that it is possible to shorten the distance between the two arrays of nozzle apertures 10 and 10′ independently of the distance between the two arrays of piezoelectric elements 12 and 12′.

In Fig. 5, which shows a second embodiment, reference numeral 32 represents a vibration plate, on the surface of which a ridge strip portion 32a is formed so as to separate the array of piezoelectric vibrators 12 from the array of piezoelectric vibrators 12′, and groove portions 32b to 32e are formed to surround the respective top ends of the piezoelectric

vibrators 12 and 12'.

The reference numeral 33 represents a nozzle plate in which nozzle apertures 34 and 34' are formed so as to accord with the arrangement of the piezoelectric vibrators 12 and 12', and ridge portions 33a to 33c are formed in the opposite side and central portions, respectively, so as to form recess portions 33e and 33f constituting ink reservoirs on the top ends of the piezoelectric vibrators 12 and 12' when the nozzle plate 33 is fixed to the vibration plate 32.

In this embodiment, if the piezoelectric vibrators 12 and 12' axially expand when an electric signal of about 30 V is applied, the vibration plate 32 fixed to the top ends of the piezoelectric vibrators 12 and 12' expands so that the vibration plate 32 contacting the piezoelectric vibrators is displaced toward the recess portions 33e and 33f of the nozzle plate 33, thereby compressing the ink therein through the vibration plate 32. The compressed ink jets out as ink drops through the nozzle apertures 34 and 34' formed in the other surface.

If the application of the signal is stopped, the piezoelectric vibrators 12 contract to their initial states to make the vibration plate 33 return to its initial position, so that the ink reservoir is expanded to the volume at the time of application of no signal. Consequently, the ink in the recess portions 32b to 32e flows into the recess portions 33e and 33f

constituting ink reservoirs, thereby preparing for the next ink drop generation. According to this embodiment, no spacer member is necessary, and it is possible to simplify the assembling process.

In Fig. 6, which shows an embodiment of the drop-on-demand ink-jet printing head of a second type according to the present invention, reference numeral 40 represents a cylindrical body composed of an electrically isolating material such as ceramics. The cylindrical body 40 has openings at its opposite ends. A nozzle plate 43 having nozzle apertures 41 and 42 is fixed on the one end of the cylindrical body 40 through a bonding agent, while a base plate 44 having piezoelectric element arrays (which will be described later) is fixed on the other end of the cylindrical body 40. Piezoelectric elements 45 and 46 of these piezoelectric element arrays are disposed so that the direction of expansion/contraction is opposite to the nozzle apertures 41 and 42 when electric signals from lines 47 and 48 are applied thereto. In addition, a partition plate 49 reaching the nozzle plate 43 is provided on the base plate 44.

In the thus-arranged printing head using arrays of piezoelectric elements, if electric signals are applied to the piezoelectric elements 45 and 46 through the lines 47 and 48 and a common electrode, the base plate 44 in this embodiment, the piezoelectric elements 45 and 46 expand in the direction of lamination so that the free ends of the piezoelectric elements

45 and 46 press ink toward the nozzle apertures 41 and 42, whereby the dynamically pressurized ink enters the nozzle apertures 41 and 42 and is jetted out as ink drops to thereby form dots on the printing paper.

When the applieation of the electric signals is stopped, the piezoelectric elements 45 and 46 contract into their original states, so that ink flows into the space between the nozzle plate 43 and the piezoelectric elements 45 and 46 to thereby prepare for the next ink drop generation.

Figs. 7a and 7b show an embodiment of the inventive method of producing an array of piezoelectric elements. In Fig. 7a, reference numeral 65 represents a member in which the surface of a base plate 66 formed of a plate-like ceramic material is coated with a conductive material 67, which acts also as bonding agent. The surface of the conductive material 67 of this base plate 66 is coated with piezoelectric materials 68 and conductive materials 69 alternately in layers in the same manner as in the above-mentioned case (Figs. 3a to 3c).

In the stage where a lamination of a predetermined number of layers has been dried to a state in which it can be fired, the base plate 66, the piezoelectric materials 68 and the conductive materials 69 are fired integrally as they are. Consequently, the base plate 66, the piezoelectric materials 68 and the conductive materials 69 are bonded by the conductive layers 67 and formed integrally (in Fig. 7b). Subsequent to

the firing operation, by forming slits at a constant distance as mentioned above, it is possible to integrally form piezoelectric element arrays on the base plate 66 in which the conductive layers 67 are formed.

Moreover, since the jetting ability of liquid drops jetted from the nozzle apertures depends on the distance between the nozzle plate and the free end surface of the piezoelectric element, the value of the distance can be adjusted by grinding the part forms the free end of the piezoelectric element when the piezoelectric element is formed. In order to facilitate such adjustment, a layer S which has no relationship to piezoelectric action may be formed of a piezoelectric or electrode material in advance on the free end surface, as shown in Fig. 8, so that the layer S may be ground to carry out the adjustment working.

Fig. 9 shows another embodiment of the array of piezoelectric elements according to the present invention. As seen in the drawing, inactive layers 76 of a length corresponding to a quarter of the vibration wavelength are formed between a base plate 70 and electrodes 74, which are the closest to the base plate 70, when piezoelectric elements 78 are fixed on the base plate 70 to form a printing head assembly. Consequently, of the elastic waves produced within the piezoelectric elements, elastic waves which have propagated to the base plate 70 are reflected on the surface of the base

plate 70 because the acoustic impedance of the base plate 70 is different from that of the piezoelectric material so that the elastic waves return to the free ends while their phases are reversed by reciprocal passage through the inactive layers 76, thereby contributing to the ink drop generation.

Fig. 10 shows another embodiment of the array of piezoelectric elements according to the present invention. In this embodiment, a layer 84 of a substance of a high viscoelastic property is interposed between a base plate 80 and an array of piezoelectric elements 82 which are assembled as a printing head, or the piezoelectric elements are fixed to the base plate through a bonding agent which can maintain a high viscoelastic property upon completion of solidification, thereby forming a bonding agent layer.

According to this embodiment, since elastic waves propagating to the base plate 80 are attenuated by the viscoelastic layer 84, not only is it possible to reduce the interference of reflected waves from the base plate 80 to thereby stabilize the generation and jet of ink drops, but also it is possible to absorb the strain produced between the base plate 80 and the piezoelectric elements 82 at the time of expansion of the piezoelectric elements 82 by the viscoelastic layer 84 so as to prevent the piezoelectric elements 82 from being broken off.

On the other hand, since the piezoelectric elements expand

not only in their axial direction but also in their width direction at the time of discharging ink, a large stress acts on the bonding surface thereof with the base plate.

Fig. 11 illustrate a positive measure against such a problem. As seen in the drawing, a shallow slit 87 is formed in an array of piezoelectric elements 86 on the side thereof contacting a base plate 85 so that the slit 87 can absorb the strain in the width direction. Thus, it is possible to prevent problems such as breaking off of the piezoelectric elements 86.

Fig. 12 shows an embodiment of the above-mentioned nozzle plate. In this embodiment, a nozzle plate 92 is constituted in a manner so that a nozzle aperture 89 is formed in the area opposite to free end of each piezoelectric element 88, and an elliptical recess portion 90 is formed so as to surround the nozzle aperture 89.

According to this nozzle plate, if a signal is applied so that the free end of the piezoelectric element 88 expands toward the nozzle plate 92, ink present in the elliptical recess portion 90 is surrounded by a wall 94 of the recess portion 90 and covered from the back with the free end of the piezoelectric element 88 upon reception of dynamic pressure caused by elastic waves from the piezoelectric element 88. Its escape path being blocked, the ink concentratedly flows into the nozzle aperture 89. It is therefore possible to jet ink drops effectively with as low applied voltage as possible.

Fig. 13 shows another embodiment of the nozzle plate. In the nozzle plate of this embodiment, a groove 98 having a slightly larger width W than the width W' of each piezoelectric element 96 passes a nozzle aperture 100.

According to this embodiment, if the piezoelectric element 96 is disposed close enough for its top end to enter the groove 98, elastic waves generated by the piezoelectric element 96 apply a dynamic pressure to ink in the groove 98. Then, since the ink in the groove 98 is surrounded by the walls 102 of the groove 98 and covered from the back with the free end of the piezoelectric element 96, the ink in the groove 98 jets out from the nozzle aperture 100 effectively. When the driving signal is stopped to thereby allow the piezoelectric element 96 to contract, ink flows from a portion not opposite the piezoelectric element in the groove 98 into an area opposite the piezoelectric element, thereby preparing for the next printing operation. Although the width of the groove 98 is larger than that of the piezoelectric element 96 in this embodiment so that the top end of the piezoelectric element 96 can enter the groove 98, the width W of the groove 98 may be made smaller than the width W' of the piezoelectric element 96 to provide a space between the top end of the piezoelectric element 96 and the surface of the nozzle plate 101. In this case, ink receiving elastic waves from the piezoelectric element 96 is prevented from expanding in the direction

parallel to the nozzle plate 101 by the walls 102 of the groove 98, so that it is possible to produce ink drops effectively.

Fig. 14 shows another embodiment of the nozzle plate. In the nozzle plate of this embodiment, a recess portion 106 having substantially the same shape as a piezoelectric element is formed so as to surround a nozzle aperture 104, and grooves 108 which are shallower than the recess portion 106 are formed in both sides of the recess portion 106.

According to this embodiment, in the same manner as in Fig. 12, when a piezoelectric element 110 expands, that is, when elastic waves are produced, dynamic pressure is applied to the ink in the recess portion 106 from the piezoelectric element 110. Surrounded by the wall of the recess portion 106 and the free end surface of the piezoelectric element 110, the ink jets out through the nozzle aperture 104 effectively. On the other hand, when the piezoelectric element contracts, ink flows from the grooves 108 to the recess portion 106 suddenly, preparing for the next ink drop generation.

In order to form such a nozzle plate, a plate having a three-layer structure in which nickel plates 116 and 118 are pressed and fixed onto the opposite side of a copper plate 114, as shown in Fig. 15, is prepared, and then a recess portion and grooves are formed by an etching agent which dissolves only the nickel plates 116 and 118 selectively. Thus, it is possible to form a recess portion having an even bottom portion.

For example, to form a plate having such a three-layer structure of a copper plate 114 having a thickness of 50 μm sandwiched between nickel plates 116 and 118 each having a thickness of 25 μm, it is possible to dissolve all of the nickel plate on one surface of the copper plate at the same time as a recess portion is formed on the other surface, so that it is possible to form a nozzle plate having a groove of 50 μm in width defining a nozzle aperture.

Fig. 16 shows another embodiment of the nozzle plate. In the nozzle plate of this embodiment, because of screening the side of piezoelectric elements 128 dynamic pressure caused upon application of a signal to the piezoelectric elements is prevented from propagating to other adjacent nozzle apertures by separation walls 126, so that it is possible to prevent unnecessary ink from flowing out.

Fig. 18 shows another embodiment according to the present invention. In this embodiment, struts 130 are formed between piezoelectric elements 132 constituting a piezoelectric element array, and are fixed to a base plate 134 on which the array of piezoelectric elements is mounted, or on a nozzle plate 136.

According to this embodiment, not only it is possible to control the distance between nozzle plate 136 and each of the piezoelectric elements 132 by use of the struts 130, but also it is possible to prevent dynamic pressure from propagating between adjacent piezoelectric elements 132.

Fig. 19 shows another configuration of the struts 130 shown in Fig. 18. In this embodiment, the foregoing rectangular-prism-like piezoelectric ceramic material is fixed on a base plate 142, and then the ceramic material is cut and separated into portions 144 to form piezoelectric elements and portions 146 to form struts, the portions to form piezoelectric elements being ground a little on the side of their free ends.

In the thus-formed array of piezoelectric elements, a nozzle plate 148 is disposed so as to be in contact with the portions 146 to form struts as shown in Fig. 20, so that it is possible to make the gap between the nozzle plate and the free end of each of the piezoelectric elements be a predetermined size. Accordingly to this embodiment, not only is it possible to form struts in the process of forming an array of piezoelectric elements, but also it is possible to simplify the assembling work because of eliminating the step of attaching the strut members to the base plate.

Figs. 21a and 21b show another embodiment of the inventive method of fixing a nozzle plate. In this embodiment, a nozzle plate 150 through which nozzle apertures 152 are bored is urged against a base plate 160 by magnets 156 and 158 or springs so as to be always in contact with the free ends of piezoelectric elements 154.

In this embodiment, a voltage in the direction of contraction is applied to the piezoelectric elements 154 which

are in the position of ink drop formation. Consequently, a gap G is produced between the nozzle plate 150 and the free end surfaces of the piezoelectric elements 154 (in Fig. 21b), so that ink flows into this gap. Then, when the application of the signal is stopped, or if a signal in the direction of expansion is applied, the free ends of the piezoelectric elements 154 expand toward the nozzle plate 150.

In this process of expansion, the ink in the gap G is pressed to the nozzle aperture 152 and jetted out to the outside as an ink drop. Since the nozzle aperture 152 which has no relationship to the formation of an ink drop is made to elastically contact with the free end of the piezoelectric element 154, dynamic pressure from the adjacent piezoelectric elements does not act on the nozzle aperture 152 so that the ink can be prevented from leaking.

Although a space enabling ink to flow is formed between adjacent piezoelectric element arrays and between the piezoelectric element arrays and the base plate in the above-mentioned embodiment, a bonding agent or resin 162 having low viscosity and high elasticity at the time of solidification, for example, an epoxy-system bonding agent, ultraviolet-ray setting resin such as G11 or G31 made by Asahi Chemical Industry Co., Ltd., or ultraviolet-ray setting silicon rubber such as TUV6000 or TUV 602 made by Toshiba Silicon Co., Ltd., is injected and solidified in portions except for the free end

surfaces of the piezoelectric elements 160, as shown in Figs. 22a to 22c, to thereby reduce the influence of the piezoelectric elements 160 to vibration as much as possible, so that it is possible to reinforce the mechanical strength of the piezoelectric elements 160 and more ensure the electric insulation of the conductive layers.

Figs. 23a and 23b show an embodiment of a drop-on-demand ink-jet printing head of a third type according to the present invention. In this embodiment, piezoelectric elements 172 and 174 are arrayed on a base plate 166 through conductive spacers 168 and 170 so that the direction of lamination of the piezoelectric elements is parallel to the base plate 166 and the free ends of the piezoelectric elements are separated from each other by a predetermined space. In this space, a separation wall member 176 is disposed with predetermined gaps from the respective free ends of the piezoelectric elements 172 and 174.

In a nozzle plate 178, nozzle apertures 180 and 182 are formed in opposition to the gaps between the separation wall member 176 and the respective free ends of the piezoelectric elements 172 and 174, and fixed at predetermined intervals through a spacer 184. An ink tank 186 communicates with the nozzle apertures 180 and 182 through communication holes 188 and 190.

Figs. 24a to 24c depict a method of forming the above-

mentioned piezoelectric element array. As seen in these drawings, spacer members 196 and 198 are fixed to a member 194 corresponding to the base plate 166 in Figs. 23a and 23b through a bonding agent (in Fig. 24a). In this state, piezoelectric element plates 200 and 202, which are the same as those shown in Fig. 3, are fixed at their one ends through a conductive bonding agent so that the conductive layers on their one side are on the side of the spacers 196 and 198 (Fig. 24b). Next, slits 204 and 206 are formed in the thickness of the piezoelectric element plates at predetermined intervals extending parallel to the direction of lamination of the piezoelectric element plates 200 and 202 (Fig. 24c). Consequently, piezoelectric elements 205 and 207 separated from each other by the slits 204 and 206 are formed on the base plate 194 in a manner so that electrodes on one side are commonly connected to each other by the spacers 196 and 198.

In this embodiment, if a signal is applied to the piezoelectric elements 172 and 174 to form dots (Fig. 23a and 23b), a voltage is applied to the respective piezoelectric layers of the piezoelectric elements 172 and 174 through conductive layers 171 and 173 of the piezoelectric element 172 and conductive layers 175 and 177 of the piezoelectric element 174 at the same time, so that the sum of expansion force of the respective piezoelectric layers acts on the free ends. Accordingly, the ink between the separation wall member 176 and

the free end of the piezoelectric element 174 is pressed out from the space and jets out to the outside from the nozzle aperture 182. When the application of the voltage to the piezoelectric element 174 is stopped, the piezoelectric element contracts, so that ink flows from the ink tank 186 into the space, thereby preparing for the next dot generation.

Although piezoelectric elements are fixed in the form of a cantilever shape by a spacer in a printing head shown in Figs. 23a and 23b, as shown in Fig. 25a, portions of piezoelectric element plates 210 and 212 projecting over spacers 214 and 216 are fixed to a base plate 220 by a bonding agent or resin 218 having a low viscosity and a high elasticity at the time of solidification, for example, an epoxy-system bonding agent, ultraviolet-ray hardening resin such as G11 and G31 made by Asahi Chemical Industry Co., Ltd., or ultraviolet-ray setting silicon rubber such as TUV6000 or TUV 602 made by Toshiba Silicon Co., Ltd. In this state, slits 222 are formed at predetermined intervals using a diamond cutter or the like, thereby forming piezoelectric elements 224 and 226, with their one-side surfaces being bonded to the base plate 220 (Fig. 25b).

According to such a method, it is possible to absorb the vibration produced at the time of forming the slits to thereby prevent the piezoelectric element plates from being broken off.

As shown in Fig. 26, a nozzle plate 230 is attached

through a spacer 228 to the base plate 220 on which the thus -formed piezoelectric element arrays are mounted, thereby providing a printing head the same as that shown in Fig. 23a. Reference numeral 232 in Fig. 26 represents a partition member disposed between the facing surfaces of the piezoelectric elements, and 234 and 236 represent nozzle apertures.

In this embodiment, if a voltage is applied to the piezoelectric element 224 opposite the nozzle aperture 234 to form a dot, the piezoelectric element 224 expands while transforming the bonding agent 218 elastically, pressing the ink between the partition member 232 and the free end thereof, thereby jetting the ink from the nozzle aperture 234 as an ink drop. Of course, since the force produced by the piezoelectric element 224 is extremely large, the effect of the viscosity of the bonding agent 218 is extremely small, so that the energy produced as the transformation of the piezoelectric element is not absorbed by the bonding agent.

Figs. 27a to 27c illustrate another embodiment of the inventive method of forming a piezoelectric element array, in which spacers 242 and 244 are fixed to the opposite ends of a base plate 240, and a bonding agent 246 having low viscosity and high elasticity at the time of solidification flows into a grooved portion formed by the spacers 242 and 244 (Fig. 27a). A piezoelectric element plate 248 the same as the mentioned above is fixed to the spacers 2242 and 244 with a conductive

bonding agent and to the base plate 240 with a bonding agent 246 (Fig. 27b). When the bonding agent has solidified, two slits 250 and 252 separated from each other and extending to the outer surface of the base plate 240 are formed. Next, slits 254 parallel in the oblique direction are formed at predetermined intervals so that the two ends of the piezoelectric element plates separated by the slits 250 and 252 are displaced by one-half pitch (Fig. 27c).

Consequently, the free ends of the piezoelectric elements opposite to each other with the partition member 256 therebetween are displaced by one-half pitch, so that it is possible to print dots formed by the one-side piezoelectric elements 260 between dots formed by the other side piezoelectric elements 258.

A nozzle plate 266 is prepared for the thus-arranged piezoelectric elements, with the nozzle plate 266 arranged by displacing nozzle apertures 262 in the first column and nozzle apertures 264 in the second column from each other by one-half pitch, as shown in Fig. 28.

The nozzle plate 266 is attached to the base plate 240 (Fig. 27c) through a spacer 268 as shown in Fig. 29, thereby constituting a printing head.

In this embodiment, the slits 250 and 252 form ink channels, and a portion 256 separated by these slits 250 and 252 functions as a partition member, so that when a signal is

applied to the piezoelectric elements 258a and 260, ink drops are jetting out from the nozzle apertures 262 and 264.

According to this embodiment, since a partition member and ink channels can be formed together with the formation of piezoelectric elements at the same time, it is possible to simplify the process of production, and it is also possible to improve the density of dots without making the width of the piezoelectric elements narrow.

In the printing heads of the second and third types, the entire large force produced by the thickness-wise vibration of piezoelectric elements is used, and ink is jetted out by the pressure of the piezoelectric elements, so that it is possible to produce ink drops effectively not only in the case of using a normal ink but also in the case of using an extremely high viscous ink such as hot melt ink.

Figs. 30a and 30b show an embodiment of a fourth type according to the present invention. In the drawings, the reference numeral 270 represents a lead piece composed of a high elastic spring member 272 and a piezoelectric element 274 (which will be described later) laminated on the elastic spring member 272, one end of the lead piece 270 being fixed to a spacer 276 so that the lead piece 270 faces a nozzle plate 278, the other end of the lead piece 270 being formed as a free end so that the lead piece can vibrate flexibly. Reference numeral 278 represents a nozzle plate in which nozzle apertures are

formed at positions opposite the free ends of respective ones of the lead pieces 270. The nozzle plate 278 is fixed to a base member 282 which also functions as a housing.

Figs. 31a to 31c illustrate a process of producing the above-mentioned lead piece, in which a piezoelectric element plate 292 produced by the above-mentioned process is cemented through a bonding agent to one surface of a plate 290 composed of a high elastic metal plate or ceramics constituting the above -mentioned spring plate 272 so that conductive layers 294 and 296 thereof are parallel to the plate 292, thereby constituting a plate.

The thus integrally formed structure constituted by the piezoelectric element plate 292 and the plate 290 is fixed to a spacer member 298 on its one side (Fig. 31b), and slits 300 are formed at regular intervals using a diamond cutter or the like to thereby strip lead pieces 302 with their one ends fixed to the spacer 298 and with their other ends made free (Fig. 31c).

Accordingly to this embodiment, if an electric signal in the direction of contraction of the piezoelectric element plate 292 is applied to the conductive layers 294 and 296, the free ends of the lead pieces 302 are bent toward the piezoelectric element plate 292 against the elasticity of the plate 290.

In this state, when the application of the electric signal is stopped, the elastic force stored in the plate 290 is

released so that the lead pieces 302 spring and return to their original positions.

Consequently, ink between the nozzle plate 278 and the lead pieces 270 (Fig. 30a) is pressed out toward the nozzle aperture 282 and jetted out of the nozzle aperture 282 as an ink drop.

Although the piezoelectric element plate 292 produced in advance is cemented to the plate 290 in the embodiment shown in Fig. 31, high heat-proof ceramics may be used for the plate 290, so that it is possible to omit the cementing process if the piezoelectric element plate is formed on the above-mentioned process (in Fig. 3) thereon.

Figs. 32a to 32c show another embodiment of producing a lead piece, in which a piezoelectric element plate 312 produced by the above-mentioned process is cemented to one surface of a plate 310 composed of an elastic metal plate or ceramics and constituting the above-mentioned spring plate 272 with a bonding agent so that conductive layers 314 and 316 of the piezoelectric element plate 312 are perpendicular to the plate 310 (Fig. 32a).

The piezoelectric element plate 312 and the plate 310 arranged integrally is fixed at its one end portion to a spacer member 318 (in Fig. 32b). Then, slits 320 are formed in the piezoelectric element plate 312 and the plate 310 at regular intervals using a diamond cutter or the like, so as to form

stripped lead pieces 322, one ends of which are fixed to the spacer 318 and the other ends of which are free (Fig. 32c).

According to this embodiment, if an electric signal in the direction of contraction of the piezoelectric element plate 312 is applied to conductive layers 314 and 316, the respective free ends of the lead pieces 302 are bent toward the piezoelectric element plate 312 against the elasticity of the plate 310.

In this state, when the application of the electric signal is stopped, the elastic force stored in the plate 310 is released so that the lead pieces 322 spring and return to their original positions.